USAF Experience with Hyperbaric Therapy of Altitude Decompression Sickness (1941-1999)

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Introduction

Decompression sickness (DCS) is characterized by a plethora of protean symptoms. It can range from mildly annoying to life threatening. Its etiology is tissue and/or vascular bubbles. Indeed, decompression sickness has been a recognized disease since its first report by Triger in 1841. (10) First noted in construction workers laboring in pressurized caissons and later in diving operations, decompression sickness was not even postulated in aviation until 1901 by von Schrotter. (8) Later (1917), Henderson popularized the concept. (11) Over the next forty years some 17,000 cases of altitude DCS were described. At least 743 were considered serious and at least seventeen were fatal. (6) However, altitude decompression sickness was not treated with recompression until Behnke employed it in 1941. (6) Despite his apparent success, supportive care remained the standard. Then, in 1959, under the most extreme of clinical circumstances (DCS shock), Donnell and Norton essentially plucked an aviator from the brink of death with recompression. Thirty-eight hours after entering the chamber the pilot emerged symptom free. (7) This spectacular success launched the research underpinning today's treatment regimen for altitude decompression sickness. Indeed, this paper describes the USAF treatment effort over the last fifty-eight years.

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Materials and Methods

In this review, 145 cases studied by Davis et al (1977) will be examined in conjunction with the 528 cases studied by Weien and Baumgartner (1990). (6,19) These cases represent USAF hyperbaric therapy for altitude decompression sickness from 1941-1986. Since that time no comprehensive examination of USAF hyperbaric therapy has been performed. As a result, the last thirteen years (1987-1999) of USAF hyperbaric therapy was examined.

The research records maintained at the Davis Hyperbaric Laboratory (USAF School of Aerospace Medicine; Brooks AFB, Texas) were reviewed. By regulation, all cases of decompression sickness treated with hyperbaric therapy are reported to the Davis Hyperbaric Laboratory. These reports consist of Air Force Form 1352 (Hyperbaric Patient Information and Therapy Record), Air Force Form 361 (Chamber Reactor/Treatment Report), and Standard Form 502 (Medical Record---Narrative Summary). In addition, other information sources include in-patient, transfer, and aeromedical summaries.

A list of DCS victims was generated from the laboratory's database. This list included every treatment case reported to the laboratory from 1 January 1987 to 31 December 1999. Each record was then individually recovered and information extracted using a detailed two-page survey. The records were found in three formats: scanned onto a CD-ROM (1987-1990), scanned onto Canonfile diskettes (1991-1994), and hard-copy paper (1995-1999). Tracking record numbers, patient names, and birth-dates proved inconsistent. As a result, every record within the laboratory database was examined and cross-referenced to the computer listing. Interestingly, the earlier records closely matched the computer listing; however, the later records did not come close. By individually examining each database record a significant number of cases (not on the computer listing) were discovered. Although missed records are not likely, it is possible.

Once a record was accessed, it was extracted onto the two-page survey. Here, demographic information, exposure data, predisposing factors, symptom onset, symptoms and signs, diagnosis, disease progression, treatment and outcome data, and complications were recorded. No identifying personal information was obtained.

A total of 729 records documenting treatment for decompression illness were scrutinized. Of these, nineteen proved not to have DCS. Another seven did not have enough information to be of any value. Twenty had arterial gas embolism and 203 were diving DCS. The remaining 480 cases were altitude decompression sickness.

The present effort incorporates not only the most recent 480 cases, but also the 145 cases of Davis et al and the 528 cases of Weien and Baumgartner. Thus, the substance of this review spans approximately 58 years and summarizes the therapeutic outcome of hyperbaric therapy for some 1153 cases of altitude decompression sickness.

Results and Discussion

Exposure

The bulk of altitude decompression sickness in the USAF results from chamber operations (93%). From 1941-1976 chamber operations accounted for 88% of cases. (6) From 1977-1986 chamber operations accounted for 92% of cases. (19) And, from 1987-1999 chamber operations accounted for 91% of cases.

Type of Altitude Exposure			
	Chamber	Operations	unclear
1941-1976	131	14	
1977-1986	507	21	
1987-1999	437	42	1
Totals	**93%**	**7%**	

It is interesting to note that 7% of the cases came from military operations. The earlier reports do not specify aircraft type; however, the most recent review found thirteen different aircraft. These ranged from a helicopter to a high altitude parachutist to a U-2. Of note, the U-2 was responsible fourteen of the forty-two operationally-attributed cases of DCS.

As expected, the maximum altitude attained during exposure reflected the training profiles. Almost a quarter of the cases were in the 20,000-25,000 feet range; almost a third were in the 30,000-35,000 feet range; and, again, almost a quarter were in the >35,000 feet range. For years the Type I "flight" to 35,000 feet was used for initial training. In addition, training in a Type II "flight" to 43,000 feet was routine for initial training. And, refresher training, FAA training, and flight nurse training all used "flight" profiles to 25,000 feet. (9) Clearly, the more common the "flight" profile the more common the altitude DCS. Interestingly, operational cases were more common below 25,000 feet.

Maximum Altitude of Exposure						
	< 20,000	20-25,000	25-30,000	30-35,000	> 35,000	unclear
1941-1976	5	14	11	51	63	1
1977-1986						
1987-1999						
----Chamber	11	118	61	147	87	14
----Operations	10	12	9	4	4	3
Totals	**4%**	**23%**	**13%**	**32%**	**24%**	**3%**

Demographics

When looking at chamber operations either the student or the inside observer (IO) can fall prey to altitude decompression sickness. There seems to be no clear predilection. Three time segments were studied and each had a different IO : student ratio. Exposure data was available from 1996 and 1997 at Brooks AFB. There was a four-fold difference in DCS rates between the student (0.422%) and inside observer (0.097%). In contrast, Davis et al (1973-1976) reported a three-fold greater incidence of DCS among inside observers (0.064% versus 0.020%) while Weien & Baumgartner showed no difference. (6,19)

Incidence of Chamber DCS (in percent)			
	1973-1976	1977-1987	1996-1997
Inside Observer (IO)	0.064%	0.058%	0.097%
Student	0.020%	0.058%	0.422%
IO : Student Ratio	**3 to 1**	**1 to 1**	**1 to 4**

Additionally, a review of the US Navy experience mirrors that of Davis et al. Only one study period (1959-1968) showed a student predominance. In fact, from 1972 through 1988 Navy inside observers suffered significantly more DCS than students. (3)

Why students might suffer more DCS stems from the routine training in hypoxia recognition. During the chamber flight students will remove their oxygen mask to identify their own special hypoxic symptoms. Thus, the DCS protection of oxygen is prejudiced. Of note, the inside observers do not go off oxygen. Why the inside observers might suffer more DCS stems from their activity during the training. When tissues move against one another there is a localized reduction in hydrostatic pressure creating a "bubble-friendly" milieu. (17) Thus, the DCS protection of inaction is prejudiced. Of note, the students remain dormant throughout the training. Clearly, no explanation for this contradictory data is readily apparent. In any event, the incidence rates for both the student and the inside observer (independent of time period studied) are very low.

The student-IO differences stimulate interest in the demographics of the DCS victims. The most recent review revealed no surprises. As expected, there was an overwhelming preponderance of young people. Over half were between 20-30 years of age and 85% were under 35 years. Eighty percent were Caucasian with almost 90% Air Force personnel. Interestingly, aircrew made up less than 20% of the cases. The vast majority was otherwise (ie, students, technicians, physiologists).

Gender Distribution of DCS			
	Male	Female	Female/Male Incidence
1941-1976	128	20	
1977-1986	334	95	4 to 1
1987-1999	318	162	
Totals	**74%**	**26%**	

The one demographic factor examined by all three studies was gender. Clearly, there is an overall male predominance of cases. However, over the last thirteen years a full third of the DCS was in females. Contrast this to the USAF in general. From 1980-1994 women made up only 12.7% of the active duty USAF personnel. (1) This certainly suggests an over-representation of DCS with women. Indeed, the concept of female predisposition is not new. Bassett, in a retrospective review, reported a ten-fold greater incidence of chamber-induced DCS in women. (4) Similarly, Weien and Baumgartner also observed a significant difference. They reported a four-fold greater incidence in females from 1977 to 1986 (0.206% versus 0.048%). (19) In addition, Bangasser, in a diving survey, discovered a three-fold greater incidence in female diving instructors and Leger Dowse et al, in a large diving survey performed in the United Kingdom, found a two-fold greater incidence. (2,14) These observed differences have been variously attributed to fat and/or hormones. (15,16,18) In any event, again, the actual rates of decompression sickness are very low.

Symptomotology

Symptom presentation certainly reflects the literature---almost all instances of decompression sickness present within the first 24 hours after an exposure. (10,12,13) In 1137 cases of altitude decompression sickness 60% presented at altitude or within two hours of exposure.

Onset of Symptoms

		Ground		
	at Altitude	< 2 hours	> 2 hours	unclear
1941-1976	72	43	23	7
1977-1986	123	173	225	
1987-1999				
----Chamber	94	158	186	9
----Operations	23	12	7	
Totals	**27%**	**33%**	**38%**	**1%**

This was more closely examined during the last thirteen years. Again, a full 61% of cases presented at altitude or within 2 hours of exposure. Within 10 hours of exposure 83% had symptoms and within 20 hours 94% had symptoms. At 25 hours 97% were symptomatic. Only 3% of cases appeared beyond the 25 hour point.

Over the past several decades the symptom patterns have changed. In fact, there seems to be an increasing variety of patterns observed. Excluding shock, Davis et al noted nine patterns, Weien and Baumgartner described eleven patterns, and, most recently, nineteen different patterns were encountered. This may well reflect a greater reliance on descriptive diagnosis.

Patterns of Altitude DCS

	Number of Patterns	Type I	Type II
1941-1976	14	61%	39%
1977-1986	11	80%	20%
1987-1999	19	75%	25%

Type I decompression sickness refers to skin involvement (itch, rash, lymphatics), "bends" (arthralgia, myalgia), and peripheral nervous system involvement (tingling/numbness/temperature sensations without focal findings). (6,19) The inclusion of peripheral nervous system in Type I decompression sickness is limited to altitude DCS. In no way should this symptom complex be considered Type I DCS in caisson or diving DCS. Type II decompression sickness refers to neurologic involvement (with focal findings), "chokes" (pulmonary involvement), abdominal/pelvic pain, and shock.

Although the number of symptom patterns have changed over the decades, the most common patterns have remained the same. *Bends alone* predominates at ~60%. The next most common pattern is *neurologic alone* at ~10% followed *by bends plus neurologic* at ~8%. Any combination of Type I and Type II symptom patterns make up the remainder of the case presentations.

Treatment

Throughout the 58 years of this review 95-98% of altitude decompression sickness has been successfully treated with recompression. Clearly, hyperbaric therapy works and remains the standard of care.

Most recently (1987-1999), hyperbaric therapy was 95% successful. However, there were 38 instances of recurrence and 48 instances of tailing treatments. Only 3.5% of cases had permanent residual (ie, joint ache, sensory deficit, headache). Interestingly, Treatment Table 5 (TT5) was 80% successful when applied within the first ten hours of symptoms. Of note, this does not include any delay to symptom presentation (~ 40% presented with a greater than 2 hour delay). Equally fascinating, Ground Level Oxygen (GLO) succeeded 20% of the time. Of note, effective use of GLO without hyperbaric therapy was not examined in this study.

Treatment Table Outcomes (percent success)						
	TT 1-4	TT 5	TT 6	TT 8	other	**Overall Success**
1941-1976	78%	99%				**98%**
1977-1986		100%	98%	100%		**98%**
1987-1999		79%	89%	80%	43%	**95%**

Complications of Hyperbaric Therapy

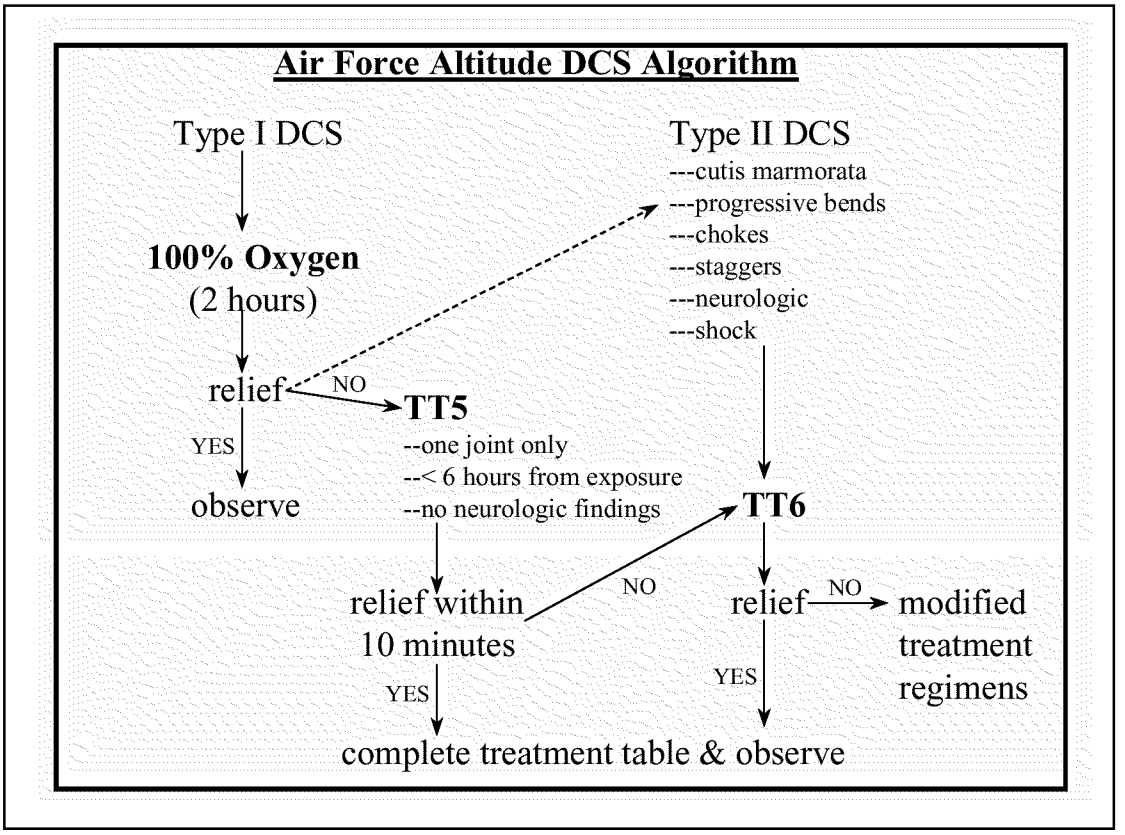
As with any therapeutic intervention complications can happen. Over the last thirteen years only fifty-three complications were encountered. As expected, ear block (~50%) and pulmonary oxygen toxicity (~36%) predominated. There were two seizures (central neurologic oxygen toxicity) and two claustrophobic reactions. No permanent sequelae were documented.

Complications of Treatment (1987-1999)		
Ear Block		26
---myringotomy	2	
Pulmonary Oxygen Toxicity		19
CNS Oxygen Toxicity		6
---seizure	2	
Claustrophobia		2
Totals		**53**

Air Force Altitude DCS Treatment Algorithm

During the last half century an algorithm for the treatment of altitude decompression sickness has been developed by the USAF. It is apparent that the hyperbaric therapy portion of this algorithm works (95-98% successful).

Documented success with TT5 and anecdotal success with GLO outside the parameters of the algorithm suggest that more oxygen and less pressure might well be considered. A natural consequence of this thinking is to revisit both TT5 and GLO. (5) Indeed, future investigations may well demand a new iteration of the algorithm.



Summary

This study reviewed 58 years hyperbaric therapy for altitude decompression sickness in the USAF. It incorporates the studies of Davis et al and Weien and Baumgartner. (6,19) To their work (1941-1986) is added another report (1987-1999).

This study confirms the continued success of hyperbaric therapy for altitude decompression sickness documenting a 95-98% success rate. It also reaffirms that most cases are associated with altitude chamber training. In fact, the maximum altitude breakdown clearly reflects the chamber training profiles. Most symptoms appear within two hours of exposure and Type I symptoms predominate. Indeed, the most common symptom pattern is bends alone. And, as with any medical treatment, there are complications, but there were no sequelae of these complications.

This study did raise several interesting questions worthy of future attention. Are females more susceptible than males? If so, why? Why do inside observers and students have different rates of DCS? Furthermore, why are the observations to date conflicting? And, finally, can the Air Force treatment algorithm be tweaked to more efficiently use GLO and TT5?

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